MODELING THE EFFECTS OF MONOLITH PERMEABILITY AND LEAD DIFFUSION COEFFICIENTS ON THE POTENTIAL LEAD CONCENTRATIONS AT THE KASSOUF-KIMMERLING SUPERFUND SITE IN TAMPA, FLORIDA

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Modeling the Effects of Monolith Permeability and Lead Diffusion Coefficients on the Potential Lead Concentrations at the Kassouf-Kimerling Superfund Site in Tampa, Florida

Background

Through contracts with Recycle Incorporated and OHM Remediation Services Corporation, I have been asked to evaluate the requirements for the monolith permeability and lead diffusion coefficients in the case of the proposed remedy at the Kassouf-Kimerling site. I am the principal scientist that developed a similar remedy at the Pepper's Steel and Alloys Site in Medley, Florida\(^1\) in 1986 through 1988. Therefore, I will use the same reasoning that led to the choices of these parameters that led to that successful site closure\(^2\). After over four years of groundwater monitoring at the Medley site, the basis for the choices for the permeability and lead diffusion coefficients are validated by actual field data.

\(^1\) L. R. Dole, "In Situ Immobilization of PCBs at Pepper's Steel and Alloys Site: A Success Story," Proceedings of the PCB Forum, August 29-30, 1989, Houston, TX, PenWell Conferences, 3050 Post Oak Boulevard, Houston, TX 77056, August 1989.

Permeability

Permeability is the principal parameter for ensuring long-term durability. Any potentially disruptive scenario involves the permeation of the monolith fabric by some aggressive agent. Therefore, low permeability prevents the intrusion of water, chloride, sulfate, or oxygen. For example, ancient Chinese tombs constructed of impermeable soft clay have successfully resisted water and oxygen penetration for three thousand years. After three millennia, the garments are still pliable, and DNA scans can be performed on the human tissues. The 4" to 6" thickness of soft clay walls had less than 50 psi of unconfined compressive strength (UCS) and still provided complete isolation for millennia.

In an active hydraulic setting, the permeability of the monolith must be at least 100 times less than the surrounding soils. Then, a particle of water accelerated by a gradient will travel around the monolith as shown in Figure 1, instead of through it. Advection through the waste mass is prevented\(^3\), and any potential releases of contaminants are controlled by diffusion. To reach the biosphere, a waste particle must diffuse through the fabric of the mass in order to reach the surface of the monolith. Given a geochemically stable monolith matrix and low diffusion coefficients, the monolith can sequester hazards for geological epochs.

\[ \text{GROUNDWATER FLOWS AROUND} \]

\[ \text{FLOW} \quad \text{SOIL} \quad K_{\text{solid}} \ll K_{\text{soil}} \]

\[ \text{IF SOLID 100 TIMES LOWER IN PERMEABILITY} \]

Figure 1  At the Kassouf-Kimerling site a monolith with a permeability of less than $5 \times 10^{-6}$ cm/s will prevent advection.

Appendix I shows the case at the Kassouf-Kimerling Superfund Site where the soils have permeabilities ranging from $2.2 \times 10^{-2}$ to $4.6 \times 10^{-3}$ cm/s. These permeabilities control the rate at which groundwater moves across the site. The local groundwater gradient is 0.00005, and the site soils have a soil porosity of 30% by volume. These conservative gradient and porosity data are based on general regional conditions and represent 'worst-case' conditions.

Given these permeabilities, the range of movement of ground water in the soil from the gradient is between 3,796 ft to 793 ft per millennium, when adjusted for the pore volume of the soil. If the monolith has a permeability of $5 \times 10^{-6}$ cm/s and a porosity of 23% by volume, water could only travel a distance of 1.125 ft inside the monolith during the same time. Again, this monolith water-particle travel distance is adjusted for its pore volume.

The proposed Kassouf-Kimerling monolith will have the approximate dimensions of 700 ft long by 60 ft wide by 10.5 ft thick. Then, outside of the monolith, a groundwater particle travels 4.99 to 1.04 relative monolith half-perimeters (760 ft) in a millennium. This is compared to inside the monolith where the water particles can only travel 0.002 relative monolith lengths (700 ft) in the same period. Based on the site's soil permeability range, the ratios of outside-over-inside relative travel lengths are from 650 to 3,107 times. This ratio relates to a conservative leachate dilution factor that does not include any additional dilution by rainfall. Clearly, the advective contribution to the potential transport of contaminants from the interior of the monolith is negligible when its permeability is less than $5 \times 10^{-6}$ cm/s.

In Appendix I, the relative water particle travel model is applied to cases of theoretical monoliths with permeabilities between $5 \times 10^{-8}$ to

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$5 \times 10^{-5}$ cm/s. The dilutions for both extremes in the site soil permeabilities are calculated. Figure 2 and Table I summarize the results of these calculations. This analysis conservatively assumed a TCLP leachate concentration for lead of 330 ppb, even though many TCLP results by OHM are less than 100 ppb for lead. Recent results from another site show lead below detection limits in laboratory expressed porewater\(^5\). Using ranges of these dilution factors and the conservative 330 ppb TCLP leachate case, the model in Appendix I calculates a potential lead concentrations at the down-gradient edge of the waste form.

At the Kassouf-Kimerling Superfund Site, a permeability of $5 \times 10^{-6}$ cm/s is adequate to protect the environment and human health. The dilution factors range from 650 to 3,107 times, resulting in concentrations of 0.5 to 0.1 ppb of lead. These estimates are very conservative. Normally, the TCLP lead concentrations are below 100 ppb for lead, and this analysis is based on 330 ppb. Even if the monolith's leachability were as high as 5 ppm, the TCLP limit for lead, the groundwater dilution would be to

7.7 ppb to 1.6 ppb, which is still below the MCL for lead in the groundwater and is still protective of the environment and human health.

Also, this analysis does not consider additional dilution from the 60 inches of annual rainfall in this region. In the subsequent diffusion analysis in Appendix II, the rainfall on the monolith is over a hundred times greater than the groundwater flux. Consideration of the rainfall in this scenario would greatly reduce these calculated lead concentrations.

<table>
<thead>
<tr>
<th>Monolith Permeability, cm/s</th>
<th>Dilution Factor Ranges</th>
<th>Dilution Adjusted TCLP Concentration Ranges, ppb</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Permeability 4.6x10^-3 cm/s</td>
<td>65 — 311</td>
<td>5 — 1</td>
</tr>
<tr>
<td>High Permeability 2.2x10^-2 cm/s</td>
<td>325 — 1,554</td>
<td>1.0 — 0.21</td>
</tr>
<tr>
<td>Low Permeability 4.6x10^-3 cm/s</td>
<td>650 — 3,107</td>
<td>0.51 — 0.11</td>
</tr>
<tr>
<td>High Permeability 2.2x10^-2 cm/s</td>
<td>3,248 — 15,540</td>
<td>0.10 — 0.02</td>
</tr>
<tr>
<td>Low Permeability 4.6x10^-3 cm/s</td>
<td>6,496 — 31,070</td>
<td>0.05 — 0.01</td>
</tr>
<tr>
<td>High Permeability 2.2x10^-2 cm/s</td>
<td>32,480 — 155,400</td>
<td>0.01 — 0.002</td>
</tr>
<tr>
<td>Low Permeability 4.6x10^-3 cm/s</td>
<td>64,960 — 310,700</td>
<td>0.005 — 0.001</td>
</tr>
</tbody>
</table>
In addition, the short-term value at 28 days for the permeability is higher than actually expected because the curing reactions are not complete. After 60 to 120 days, the initial permeability is expected to drop by a factor of 10 fold. Also, the high carbonate ground water at this site is expected to carbonize the surface of the monolith. The groundwater reaction is shown below.

\[ Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \]

Limestone (CaCO$_3$, Calcite) accumulates in the surface pores of the monolith sealing its surface. This carbonization further reduces the permeability of the monolith with time. This effect can also heal small cracks in the surface of the monolith. As a result, the in situ permeability of the monolith will be much lower than that measured in the laboratory after 28 days.

Given these results, releases from the Kassouf-Kimerling monolith will be diffusion controlled under the expected monolith and site conditions. Then, Appendix II shows the calculation of the diffusion controlled releases from the proposed monolith at the Kassouf-Kimerling Superfund Site.

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Diffusion Coefficient

As seen above, there is no significant release of lead by advection when the permeability of the monolith is below $5 \times 10^{-6}$ cm/s. Therefore, diffusion from within the monolith mass to its surface is the most significant mechanism by which contaminants can escape the waste form. Appendix II models this case for the condition expected at the Kassouf-Kimerling Superfund Site. This analysis can be used to determine an adequate leach index or diffusion coefficient required to protect the environment and human health at this site.

The analysis in Appendix II uses the same model as the Pepper's Steel and Alloys site case. The conservative source-term diffusion model predicts the highest theoretical release rates from the monolith. However, the additives that control constituent movement within the monolith become stronger over time. Because particles must attempt to make their way to the surface of the monolith through increasing internal barriers, the potential rates of release must decrease with time.

As with permeability, aging of the monolith greatly reduces the "effective diffusion coefficients." Also, the sealing of the monolith surface pores though carbonization further reduces the diffusion coefficients. This

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model is conservative because it overestimates the calculated releases by factors ranging from 20 to 125 times\(^9\).

Based on the ANS 16.1 source-term model, this general equation describes the decrease in release-rate with time\(^10\).

\[
\frac{dF(t)}{dt} = \frac{S}{V} \sqrt{\frac{De}{\pi t}}
\]

\(F(t) = \text{Fractional Release with time, } t\)
\(S = \text{Surface Area, cm}^2\)
\(V = \text{Volume, cm}^3\)
\(De = \text{Effective Diffusion Coefficient, cm}^2s^{-1}\)
\(\pi = 3.14159265...\)

In Appendix II, this conservative model is applied to the proposed monolith and site conditions at the Kassouf-Kimerling Superfund Site. The estimated mass of lead-contaminated soils is 15,000 tons. With an average density of 88.9 pounds per cubic foot (1.2 tons per cubic yard), the estimated volume of contaminated soils is 13,000 cubic yards. With a 30% volume bulking during treatment, the final monolith will be approximately 16,260 cubic yards (density of 120 pounds per cubic foot). The binder addition is

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\(^9\) Ibid, Dole, *PSA Success Story*, Section 4.0, pp. 45-56.

estimated to be 0.8 tons of admix to 1 ton of wet soil. Therefore, the mass dilution factor will be 1.8 times.

The clean-up at this site is to TCLP leaching level in the untreated soil of less than 5 ppm. Based on this and site data, the average total lead concentration in the untreated soil is conservatively estimated to be 2,500 ppm. While some total concentrations of lead at this site may exceed this level, most of the soil to be treated will be at a much lower level.

After admix mass dilution (factor 1.8) and a 30 volume percent increase, the monolith will average about 1,400 ppm of total lead. The length and width of the monolith is to be 700 ft and 60 ft, respectively. Therefore, the average thickness of the monolith will be approximately 10.5 ft. The permeability of the monolith will be less than $5 \times 10^{-6}$ cm/s, and no significant advection can occur through the waste form.

The site soils are taken to have a 'worst-case' permeability of $4.6 \times 10^{-3}$ cm/s, and there is only a 0.00005 groundwater gradient across the site. Taking the lowest site permeability and this very low gradient, the model calculates the lowest dilution by groundwater. Also, the 'worst-case' monolith is placed lengthwise with its smallest cross-section to the gradient, further minimizing groundwater dilution. The 60 inches of average annual rainfall is assumed to be continuous. In this model, the entire surface of the monolith is constantly awash in rain and/or groundwater.

In Appendix II, the average concentrations over the first millennia are calculated for a point within 5 feet of the monolith on its down gradient end. There is (1) no occlusion of the surface by contact with adjacent soil or rock, (2) no carbonization of the surface by CO$_2$ from the air or CaHCO$_3$ from the groundwater, and (3) no further densification of the matrix and reduction in the diffusion coefficient with age. This is a conservative model.

This model was applied to cases where the monolith's effective diffusion coefficients for lead were varied from $1 \times 10^{-10} \text{cm}^2/\text{s}$ (LI=10) to $5 \times 10^{-14} \text{cm}^2/\text{s}$ (LI=13.3). LI, the leach index, is defined by the ANS 16.1 short
term leach procedure and is the negative $\log_{10}$ of the effective diffusion coefficient\textsuperscript{11}.

In Appendix II, the fractional releases in pounds of lead were calculated for the first 1,000 years and divided by the sum of groundwater and rain that would have fallen on the monolith plus a five-foot zone-of-influence (or berm) around the monolith. Then, the monolith collects rain from over 49,700 square feet. In the first 1,000 years, $1.55 \times 10^{10}$ pounds of precipitation washes over the monolith. The concentrations in Figure 3 and Table II are a result of the calculated fractional release of lead by diffusion divided by this mass of precipitation, which is over 100 times greater than the percolating groundwater mass.

\begin{figure}
\centering
\includegraphics[width=\textwidth]{figure3.png}
\caption{A lead diffusion coefficient of $1 \times 10^{-12}$ cm$^2$/s (LI$\geq$12) will protect the environment and human health at this site.}
\end{figure}

### Table II

<table>
<thead>
<tr>
<th>Monolith diffusion coefficient, cm²/s</th>
<th>Fraction released after 1,000 years</th>
<th>Average concentration of lead, ppb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1x10⁻¹⁰</td>
<td>0.01499</td>
<td>70</td>
</tr>
<tr>
<td>1x10⁻¹¹</td>
<td>0.00474</td>
<td>22</td>
</tr>
<tr>
<td>5x10⁻¹²</td>
<td>0.00335</td>
<td>16</td>
</tr>
<tr>
<td>1x10⁻¹²</td>
<td>0.0015</td>
<td>7.0</td>
</tr>
<tr>
<td>5x10⁻¹³</td>
<td>0.00106</td>
<td>5.0</td>
</tr>
<tr>
<td>1x10⁻¹³</td>
<td>0.00047</td>
<td>2.2</td>
</tr>
<tr>
<td>5x10⁻¹⁴</td>
<td>0.00034</td>
<td>1.6</td>
</tr>
</tbody>
</table>

These results show that the calculated lead concentration do not drop below current drinking water standards of 15 ppb for lead until the effective diffusion coefficient is less than 5x10⁻¹² cm²/s (LI≥11.3). With an effective diffusion coefficient of 1x10⁻¹² cm²/s (LI=12), the lead concentration drops to about 7 ppb, which is half the MCL for groundwater. Therefore, a LI of 12 or greater is sufficient to protect the environment and human health on this site.
Conclusions

Given the Kassouf-Kimerling Superfund Site conditions, a solidification/stabilization remedy that results in a monolith with a permeability below $5 \times 10^{-6}$ cm/s and a lead diffusion coefficient equal or below $1 \times 10^{-12}$ cm$^2$/s (LI$\geq$12) will protect the environment and human health in Tampa, Florida. These in situ performance criteria can be reached by current formulations.
Appendix I

Effect of Monolith Permeability on Water Advection at the Kassouf-Kimerling Superfund Site
Dilution effect of relative transport through and around an underground monolith in the water table at the 58th Street landfill (assuming a TCLP of 330 ppb).

<table>
<thead>
<tr>
<th>Monolith Permeability, cm/s</th>
<th>Low Permeable Soil, 4.6E-3 cm/s</th>
<th>Dilution Factor Ranges</th>
<th>High Permeable Soil, 2.2E-2 cm/s</th>
<th>Dilution Adjusted TCLP Concentration Ranges, ppb</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.00E-05</td>
<td>65 - 311</td>
<td>5.08 - 1.061</td>
<td>1.015 - 0.212</td>
<td></td>
</tr>
<tr>
<td>1.00E-05</td>
<td>325 - 1,554</td>
<td>0.508 - 0.106</td>
<td>0.102 - 0.021</td>
<td></td>
</tr>
<tr>
<td>5.00E-06</td>
<td>650 - 3,107</td>
<td>0.051 - 0.011</td>
<td>0.010 - 0.002</td>
<td></td>
</tr>
<tr>
<td>1.00E-06</td>
<td>3,248 - 15,540</td>
<td></td>
<td>0.0051 - 0.0011</td>
<td></td>
</tr>
<tr>
<td>5.00E-07</td>
<td>6,496 - 31,070</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.00E-07</td>
<td>32,480 - 155,400</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.00E-08</td>
<td>64,960 - 310,700</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Calculated down-gradient advection leachate concentration as a function of monolith permeability (TCLP of 330 ppb for lead).

- Soil Low Perm = 4.6E-3 cm/s
- Soil High Perm = 2.2E-2 cm/s
Site Soil Permeability = $2.2 \times 10^{-2}$
Comparison of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith:

\[ D_{\text{mono}} := 5 \cdot 10^{-5} \text{ cm s}^{-1} \]

Pore_Mono := 0.23

L := 700 ft W := 60 ft

Half_Mono_Perimeter := L + W

Half_Mono_Perimeter = 760 ft

Darcy permeability of the site soil:

\[ D_{\text{soil}} := 2.2 \cdot 10^{-2} \text{ cm s}^{-1} \]

Pore_Soil := 0.3

Gradient := 0.00005

Water particle travel in 1,000 years:

\[ \text{Dist}_{\text{mono}} := \frac{D_{\text{mono}} \cdot \text{Gradient} \cdot 1000 \cdot \text{yr}}{\text{Pore}_{\text{mono}}} \]

\[ \text{Dist}_{\text{mono}} = 11.254 \text{ ft} \]

\[ \text{Dist}_{\text{soil}} := \frac{D_{\text{soil}} \cdot \text{Gradient} \cdot 1000 \cdot \text{yr}}{\text{Pore}_{\text{soil}}} \]

\[ \text{Dist}_{\text{soil}} = 3.796 \cdot 10^3 \text{ ft} \]

Relative Distance := \( \frac{\text{Dist}_{\text{mono}}}{\text{Dist}_{\text{soil}}} \)

Relative Distance = 0.003

Monolith lengths travel in 1,000 years for an internal water particle:

\[ \text{Monolith Lengths internal} := \frac{\text{Dist}_{\text{mono}}}{L} \]

Monolith Lengths internal = 0.016

Monolith lengths travel in 1,000 years for an external water particle:

\[ \text{Monolith Lengths external} := \frac{\text{Dist}_{\text{soil}}}{\text{Half}_{\text{mono}} \text{Perimeter}} \]

Monolith Lengths external = 4.995

\[ \text{Ratio External over Internal Length} := \frac{\text{Monolith Lengths external}}{\text{Monolith Lengths internal}} \]

Relative distance traveled by a water particle around the monolith rather than through it.

\[ \text{Ratio External over Internal Length} = 310.702 \]
Darcy permeability of Monolith:  
\[
\text{Dmono} := 1 \times 10^{-5} \text{ cm/s}
\]

Pore_Mono := 0.23

L := 700 ft  
W := 60 ft

Half_Mono_Perimeter := L + W

Half_Mono_Perimeter := 760 ft

Darcy permeability of the site soil:  
\[
\text{Dsoil} := 2.2 \times 10^{-2} \text{ cm/s}
\]

Pore_Soil := 0.3

Gradient := 0.00005

Water particle travel in 1,000 years:

\[
\text{Dist}_\text{Mono} := \frac{\text{Dmono} \times \text{Gradient} \times 1000 \text{ yr}}{\text{Pore}_\text{Mono}}
\]

\[
\text{Dist}_\text{Mono} = 2.251 \text{ ft}
\]

\[
\text{Dist}_\text{Soil} := \frac{\text{Dsoil} \times \text{Gradient} \times 1000 \text{ yr}}{\text{Pore}_\text{Soil}}
\]

\[
\text{Dist}_\text{Soil} = 3.796 \times 10^3 \text{ ft}
\]

Relative_Distance := \frac{\text{Dist}_\text{Mono}}{\text{Dist}_\text{Soil}}

Relative_Distance = 5.929 \times 10^{-4}

Monolith lengths travel in 1,000 years for an internal water particle:

\[
\text{Monolith}_\text{Lengths}_\text{internal} := \frac{\text{Dist}_\text{Mono}}{L}
\]

\[
\text{Monolith}_\text{Lengths}_\text{internal} = 0.003
\]

Monolith lengths travel in 1,000 years for an external water particle:

\[
\text{Monolith}_\text{Lengths}_\text{external} := \frac{\text{Dist}_\text{Soil}}{\text{Half}_\text{Mono}_\text{Perimeter}}
\]

\[
\text{Monolith}_\text{Lengths}_\text{external} = 4.995
\]

\[
\text{Ratio}_\text{External}_\text{over}_\text{Internal}_\text{Length} := \frac{\text{Monolith}_\text{Lengths}_\text{external}}{\text{Monolith}_\text{Lengths}_\text{internal}}
\]

Relative distance traveled by a water particle around the monolith rather than through it.

\[
\text{Ratio}_\text{External}_\text{over}_\text{Internal}_\text{Length} = 1.554 \times 10^3
\]
Comparason of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith:  
\[ D_{\text{mono}} = 5 \times 10^{-6} \text{ cm} \text{ s}^{-1} \]

Pore_Mono := 0.23

L := 700 ft  
W := 60 ft

Half_Mono_Perimeter := L + W
Half_Mono_Perimeter = 760 ft

Darcy permeability of the site soil:  
\[ D_{\text{soil}} = 2.2 \times 10^{-2} \text{ cm} \text{ s}^{-1} \]

Pore_Soil := 0.3

Gradient := 0.00005

Water particle travel in 1,000 years:

Dist_Mono := \[\frac{D_{\text{mono}} \times \text{Gradient} \times 1000 \text{ yr}}{\text{Pore}_\text{Mono}}\]
Dist_Mono = 1.125 ft

Dist_Soil := \[\frac{D_{\text{soil}} \times \text{Gradient} \times 1000 \text{ yr}}{\text{Pore}_\text{Soil}}\]
Dist_Soil = 3.796 \times 10^2 ft

Relative\_Distance := \[\frac{\text{Dist}_\text{Mono}}{\text{Dist}_\text{Soil}}\]
Relative\_Distance = 2.964 \times 10^{-4}

Monolith lengths travel in 1,000 years for an internal water particle:

Monolith\_Lengths\_internal := \[\frac{\text{Dist}_\text{Mono}}{L}\]
Monolith\_Lengths\_internal = 0.002

Monolith lengths travel in 1,000 years for an external water particle:

Monolith\_Lengths\_external := \[\frac{\text{Dist}_\text{Soil}}{\text{Half}_\text{Mono\_Perimeter}}\]
Monolith\_Lengths\_external = 4.995

Ratio_External\_over\_Internal\_Length := \[\frac{\text{Monolith\_Lengths\_external}}{\text{Monolith\_Lengths\_internal}}\]
Ratio_External\_over\_Internal\_Length = 3.107 \times 10^3

Relative distance traveled by a water particle around the monolith rather than through it.
Comparisons of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith:

\[ D_{\text{mono}} := 1 \cdot 10^{-6} \frac{\text{m}}{s} \]

Pore_Mono := 0.23

\[ L := 700 \cdot \text{ft} \quad W := 60 \cdot \text{ft} \]

\[ \text{Half Mono Perimeter} := L + W \]

Water particle travel in 1,000 years:

\[ \text{Dist}_{\text{Mono}} := \frac{D_{\text{mono}} \cdot \text{Gradient} \cdot 1000 \cdot \text{yr}}{\text{Pore Mono}} \]

\[ \text{Dist}_{\text{Mono}} = 0.225 \cdot \text{ft} \]

\[ \text{Dist}_{\text{soil}} := \frac{D_{\text{soil}} \cdot \text{Gradient} \cdot 1000 \cdot \text{yr}}{\text{Pore Soil}} \]

\[ \text{Dist}_{\text{soil}} = 3.796 \cdot 10^3 \cdot \text{ft} \]

Relative Distance := \frac{\text{Dist}_{\text{Mono}}}{\text{Dist}_{\text{soil}}}

Relative Distance = 5.929 \cdot 10^{-5}

Monolith lengths travel in 1,000 years for an internal water particle:

\[ \text{Monolith Lengths}_\text{internal} := \frac{\text{Dist}_{\text{Mono}}}{L} \]

\[ \text{Monolith Lengths}_\text{internal} = 3.215 \cdot 10^{-4} \]

Monolith lengths travel in 1,000 years for an external water particle:

\[ \text{Monolith Lengths}_\text{external} := \frac{\text{Dist}_{\text{soil}} \cdot \text{Half Mono Perimeter}}{\text{Half Mono Perimeter}} \]

\[ \text{Monolith Lengths}_\text{external} = 4.995 \]

\[ \text{Ratio External over Internal Length} := \frac{\text{Monolith Lengths}_\text{external}}{\text{Monolith Lengths}_\text{internal}} \]

Relative distance traveled by a water particle around the monolith rather than through it.

\[ \text{Ratio External over Internal Length} = 1.554 \cdot 10^4 \]
Comparasion of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith:

\[ D_{\text{mono}} = 5 \times 10^{-7} \text{ cm/s} \]

Pore Mono := 0.23

L := 700 ft

L + W := 760 ft

Darcy permeability of the site soil:

\[ D_{\text{soil}} = 2.2 \times 10^{-2} \text{ cm/s} \]

Pore Soil := 0.3

\[ \text{Gradient} = 0.00005 \]

\[ \text{Half}_\text{Mono}_\text{Perimeter} := L + W \]

\[ \text{Half}_\text{Mono}_\text{Perimeter} = 760 \text{ ft} \]

Water particle travel in 1,000 years:

\[ \text{Dist}_\text{Mono} := \frac{D_{\text{mono}} \times \text{Gradient} \times 1,000 \text{ yr}}{\text{Pore Mono}} \]

\[ \text{Dist}_\text{Mono} = 0.113 \text{ ft} \]

\[ \text{Dist}_\text{Soil} := \frac{D_{\text{soil}} \times \text{Gradient} \times 1,000 \text{ yr}}{\text{Pore Soil}} \]

\[ \text{Dist}_\text{Soil} = 3.796 \times 10^3 \text{ ft} \]

\[ \text{Relative Distance} := \frac{\text{Dist}_\text{Mono}}{\text{Dist}_\text{Soil}} \]

\[ \text{Relative Distance} = 2.964 \times 10^{-5} \]

Monolith lengths travel in 1,000 years for an internal water particle:

\[ \text{Monolith}_\text{Lengths}_\text{internal} := \frac{\text{Dist}_\text{Mono}}{L} \]

\[ \text{Monolith}_\text{Lengths}_\text{internal} = 1.608 \times 10^{-4} \]

Monolith lengths travel in 1,000 years for an external water particle:

\[ \text{Monolith}_\text{Lengths}_\text{external} := \frac{\text{Dist}_\text{Soil}}{\text{Half}_\text{Mono}_\text{Perimeter}} \]

\[ \text{Monolith}_\text{Lengths}_\text{external} = 4.995 \]

\[ \text{Ratio}_\text{External}_\text{over}_\text{Internal}_\text{Length} := \frac{\text{Monolith}_\text{Lengths}_\text{external}}{\text{Monolith}_\text{Lengths}_\text{internal}} \]

\[ \text{Ratio}_\text{External}_\text{over}_\text{Internal}_\text{Length} = 3.107 \times 10^4 \]

Relative distance traved by a water particle around the monolith rather than through it.
Comparison of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith:

\[ D_{\text{mono}} := 1 \cdot 10^{-7} \frac{\text{cm}}{\text{s}} \]

Darcy permeability of the site soil:

\[ D_{\text{soil}} := 2.2 \cdot 10^{-8} \frac{\text{cm}}{\text{s}} \]

Pore_Mono := 0.23

Pore_Soil := 0.3

\[ L := 700 \text{ ft} \quad W := 60 \text{ ft} \]

\[ \text{Gradient} := 0.00005 \]

\[ \text{Half_Mono_Perimeter} := L + W \]

\[ \text{Half_Mono_Perimeter} = 760 \text{ ft} \]

Water particle travel in 1,000 years:

\[ \text{Dist}_\text{Mono} := \frac{D_{\text{mono}} \cdot \text{Gradient} \cdot 1000 \text{ yr}}{\text{Pore_Mono}} \]

\[ \text{Dist}_\text{Mono} = 0.023 \text{ ft} \]

\[ \text{Dist}_\text{Soil} := \frac{D_{\text{soil}} \cdot \text{Gradient} \cdot 1000 \text{ yr}}{\text{Pore_Soil}} \]

\[ \text{Dist}_\text{Soil} = 3.796 \cdot 10^3 \text{ ft} \]

\[ \text{Relative_Distance} := \frac{\text{Dist}_\text{Mono}}{\text{Dist}_\text{Soil}} \]

\[ \text{Relative_Distance} = 5.929 \cdot 10^{-6} \]

Monolith lengths travel in 1,000 years for an internal water particle:

\[ \text{Monolith_Lengths_internal} := \frac{\text{Dist}_\text{Mono}}{L} \]

\[ \text{Monolith_Lengths_internal} = 3.215 \cdot 10^{-5} \]

Monolith lengths travel in 1,000 years for an external water particle:

\[ \text{Monolith_Lengths_external} := \frac{\text{Dist}_\text{Soil}}{\text{Half_Mono_Perimeter}} \]

\[ \text{Monolith_Lengths_external} = 4.995 \]

\[ \text{Ratio External over Internal Length} := \frac{\text{Monolith_Lengths_external}}{\text{Monolith_Lengths_internal}} \]

Relative distance traveled by a water particle around the monolith rather than through it:

\[ \text{Ratio External over Internal Length} = 1.554 \cdot 10^5 \]
Comparason of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith:

\[ D_{\text{mono}} = 5 \times 10^{-8} \text{ cm/s} \]

Pore Mono = 0.23

L = 700 ft  W = 60 ft

Gradient = 0.00005

\[ \text{Half Mono Perimeter} = L + W \]

\[ \text{Half Mono Perimeter} = 760 \text{ ft} \]

Darcy permeability of the site soil:

\[ D_{\text{soil}} = 2.2 \times 10^{-2} \text{ cm/s} \]

Pore Soil = 0.3

Dist Mono = \( \frac{D_{\text{mono}} \times \text{Gradient} \times 1000 \text{ yr}}{\text{Pore Mono}} \)

Dist Mono = 0.011 ft

Dist Soil = \( \frac{D_{\text{soil}} \times \text{Gradient} \times 1000 \text{ yr}}{\text{Pore Soil}} \)

Dist Soil = 3.796 \times 10^3 ft

Relative Distance = \( \frac{\text{Dist Mono}}{\text{Dist Soil}} \)

Relative Distance = 2.964 \times 10^{-6}

Monolith lengths travel in 1,000 years for an internal water particle:

\[ \text{Monolith Lengths internal} = \frac{\text{Dist Mono}}{L} \]

\[ \text{Monolith Lengths internal} = 1.608 \times 10^{-5} \]

Monolith lengths travel in 1,000 years for an external water particle:

\[ \text{Monolith Lengths external} = \frac{\text{Dist Soil}}{\text{Half Mono Perimeter}} \]

\[ \text{Monolith Lengths external} = 4.995 \]

Ratio External over Internal Length = \( \frac{\text{Monolith Lengths external}}{\text{Monolith Lengths internal}} \)

Relative distance traveled by a water particle around the monolith rather than through it.

\[ \text{Ratio External over Internal Length} = 3.107 \times 10^5 \]
Site Soil Permeability = $4.6 \times 10^{-3}$
Comparason of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith: Darcy permeability of the site soil:

\[ D_{\text{mono}} := 5 \times 10^{-5} \, \text{cm/s} \]
\[ D_{\text{soil}} := 4.6 \times 10^{-3} \, \text{cm/s} \]

\[ \text{Pore}_{\text{Mono}} := 0.23 \]
\[ \text{Pore}_{\text{Soil}} := 0.3 \]

\[ L := 700 \, \text{ft} \quad W := 60 \, \text{ft} \]
\[ \text{Gradient} := 0.00005 \]

\[ \text{Half Mono Perimeter} := L + W \]
\[ \text{Half Mono Perimeter} = 760 \, \text{ft} \]

Water particle travel in 1,000 years:

\[ \text{Dist}_{\text{Mono}} := \frac{D_{\text{mono}} \cdot \text{Gradient} \cdot 1000 \, \text{yr}}{\text{Pore}_{\text{Mono}}} \]
\[ \text{Dist}_{\text{Mono}} = 11.254 \, \text{ft} \]

\[ \text{Dist}_{\text{Soil}} := \frac{D_{\text{soil}} \cdot \text{Gradient} \cdot 1000 \, \text{yr}}{\text{Pore}_{\text{Soil}}} \]
\[ \text{Dist}_{\text{Soil}} = 793.772 \, \text{ft} \]

Relative Distance := \frac{\text{Dist}_{\text{Mono}}}{\text{Dist}_{\text{Soil}}} \]
\[ \text{Relative Distance} = 0.014 \]

Monolith lengths travel in 1,000 years for an internal water particle:

\[ \text{Monolith Lengths internal} := \frac{\text{Dist}_{\text{Mono}}}{L} \]
\[ \text{Monolith Lengths internal} = 0.016 \]

Monolith lengths travel in 1,000 years for an external water particle:

\[ \text{Monolith Lengths external} := \frac{\text{Dist}_{\text{Soil}}}{\text{Half Mono Perimeter}} \]
\[ \text{Monolith Lengths external} = 1.044 \]

\[ \text{Ratio External over Internal Length} := \frac{\text{Monolith Lengths external}}{\text{Monolith Lengths internal}} \]
\[ \text{Ratio External over Internal Length} = 64.965 \]

Relative distance traveled by a water particle around the monolith rather than through it.
Comparasion of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith:

\[ D_{\text{mono}} := 1 \times 10^{-5} \text{ cm} / \text{s} \]
\[ \text{Pore}_{\text{Mono}} := 0.23 \]
\[ L := 700 \text{ ft} \]
\[ W := 60 \text{ ft} \]

Darcy permeability of the site soil:

\[ D_{\text{soil}} := 4.6 \times 10^{-3} \text{ cm} / \text{s} \]
\[ \text{Pore}_{\text{Soil}} := 0.3 \]

Gradient := 0.00005

\[ \text{Half}_\text{Mono}_\text{Perimeter} := L + W \]
\[ \text{Half}_\text{Mono}_\text{Perimeter} = 760 \text{ ft} \]

Water particle travel in 1,000 years:

\[ \text{Dist}_{\text{Mono}} := \frac{D_{\text{mono}} \times \text{Gradient} \times 1000 \text{ yr}}{\text{Pore}_{\text{Mono}}} \]
\[ \text{Dist}_{\text{Mono}} = 2.251 \text{ ft} \]

\[ \text{Dist}_{\text{Soil}} := \frac{D_{\text{soil}} \times \text{Gradient} \times 1000 \text{ yr}}{\text{Pore}_{\text{Soil}}} \]
\[ \text{Dist}_{\text{Soil}} = 793.772 \text{ ft} \]

\[ \text{Relative} \_\text{Distance} := \frac{\text{Dist}_{\text{Mono}}}{\text{Dist}_{\text{Soil}}} \]
\[ \text{Relative} \_\text{Distance} = 0.003 \]

Monolith lengths travel in 1,000 years for an internal water particle:

\[ \text{Monolith} \_\text{Lengths} \_\text{internal} := \frac{\text{Dist}_{\text{Mono}}}{L} \]
\[ \text{Monolith} \_\text{Lengths} \_\text{internal} = 0.003 \]

Monolith lengths travel in 1,000 years for an external water particle:

\[ \text{Monolith} \_\text{Lengths} \_\text{external} := \frac{\text{Dist}_{\text{Soil}}}{\text{Half}_\text{Mono}_\text{Perimeter}} \]
\[ \text{Monolith} \_\text{Lengths} \_\text{external} = 1.044 \]

\[ \text{Ratio} \_\text{External} \_\text{over} \_\text{Internal} \_\text{Length} := \frac{\text{Monolith} \_\text{Lengths} \_\text{external}}{\text{Monolith} \_\text{Lengths} \_\text{internal}} \]

Relative distance traveled by a water particle around the monolith rather than through it.

\[ \text{Ratio} \_\text{External} \_\text{over} \_\text{Internal} \_\text{Length} = 394.825 \]
Comparson of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith:

\[ D_{\text{mono}} := 5 \cdot 10^{-10} \, \text{cm} \, \text{s}^{-1} \]

Pore_Mono := 0.23

L := 700 \, \text{ft} \quad W := 60 \, \text{ft}

Half_Mono_Perimeter := L + W

\[ H = 760 \, \text{ft} \]

Darcy permeability of the site soil:

\[ D_{\text{soil}} := 4.6 \cdot 10^{-3} \, \text{cm} \, \text{s}^{-1} \]

Pore_Soil := 0.3

Gradient := 0.00005

Water particle travel in 1,000 years:

\[ \text{Dist}_{\text{Mono}} := \frac{D_{\text{mono}} \cdot \text{Gradient} \cdot 1000 \cdot \text{yr}}{\text{Pore}_\text{Mono}} \]

\[ \text{Dist}_{\text{Mono}} = 1.125 \, \text{ft} \]

\[ \text{Dist}_{\text{Soil}} := \frac{D_{\text{soil}} \cdot \text{Gradient} \cdot 1000 \cdot \text{yr}}{\text{Pore}_\text{Soil}} \]

\[ \text{Dist}_{\text{Soil}} = 793.772 \, \text{ft} \]

Relative_Distance := \frac{\text{Dist}_{\text{Mono}}}{\text{Dist}_{\text{Soil}}} \quad \text{Relative Distance} = 0.001

Monolith lengths travel in 1,000 years for an internal water particle:

\[ \text{Monolith Lengths}_{\text{internal}} := \frac{\text{Dist}_{\text{Mono}}}{L} \]

\[ \text{Monolith Lengths}_{\text{internal}} = 0.002 \]

Monolith lengths travel in 1,000 years for an external water particle:

\[ \text{Monolith Lengths}_{\text{external}} := \frac{\text{Dist}_{\text{Soil}}}{H + \frac{\text{Half}_\text{Mono}_\text{Perimeter}}{2}} \]

\[ \text{Monolith Lengths}_{\text{external}} = 1.044 \]

\[ \text{Ratio}_{\text{External over Internal Length}} := \frac{\text{Monolith Lengths}_{\text{external}}}{\text{Monolith Lengths}_{\text{internal}}} \]

Relative distance traveled by a water particle around the monolith rather than through it.
Comparason of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith:

\[ D_{\text{mono}} = 1 \times 10^{-6} \text{ cm s}^{-1} \]

Pore_Mono := 0.23

L := 700 ft

Water particle travel in 1,000 years:

\[ \text{Dist}_\text{Mono} = \frac{D_{\text{mono}} \times \text{Gradient} \times 1000 \times \text{yr}}{\text{Pore}_\text{Mono}} \]

\[ \text{Dist}_\text{Mono} = 0.225 \text{ ft} \]

Darcy permeability of the site soil:

\[ D_{\text{soil}} = 4.6 \times 10^{-3} \text{ cm s}^{-1} \]

Pore_Soil := 0.3

Half Mono Perimeter := L + W

\[ \text{Half Mono Perimeter} = 760 \text{ ft} \]

\[ \text{Dist}_\text{Soil} = \frac{D_{\text{soil}} \times \text{Gradient} \times 1000 \times \text{yr}}{\text{Pore}_\text{Soil}} \]

\[ \text{Dist}_\text{Soil} = 793.772 \text{ ft} \]

Relative_Distance := \frac{\text{Dist}_\text{Mono}}{\text{Dist}_\text{Soil}}

\[ \text{Relative Distance} = 2.836 \times 10^{-4} \]

Monolith lengths travel in 1,000 years for an internal water particle:

\[ \text{Monolith}\_\text{Lengths}\_\text{internal} := \frac{\text{Dist}_\text{Mono}}{L} \]

\[ \text{Monolith}\_\text{Lengths}\_\text{internal} = 3.215 \times 10^{-4} \]

Monolith lengths travel in 1,000 years for an external water particle:

\[ \text{Monolith}\_\text{Lengths}\_\text{external} := \frac{\text{Dist}_\text{Soil}}{\text{Half Mono Perimeter}} \]

\[ \text{Monolith}\_\text{Lengths}\_\text{external} = 1.044 \]

Relative distance traveled by a water particle around the monolith rather than through it.
Comparaison of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith: $D_{\text{mono}} = 5 \times 10^{-7} \text{ cm/s}$

Darcy permeability of the site soil: $D_{\text{soil}} = 4.6 \times 10^{-3} \text{ cm/s}$

Pore_Mono := 0.23

Pore_Soil := 0.3

$L := 700 \text{-ft} \quad W := 60 \text{-ft}$

Gradient := 0.00005

Half_Mono_Perimeter := $L + W$

Half_Mono_Perimeter := 760 \text{-ft}

Water particle travel in 1,000 years:

$$\text{Dist}_\text{Mono} := \frac{D_{\text{mono}} \times \text{Gradient} \times 1000 \text{-yr}}{\text{Pore}_\text{Mono}}$$

$$\text{Dist}_\text{Mono} = 0.113 \text{-ft}$$

$$\text{Dist}_\text{Soil} := \frac{D_{\text{soil}} \times \text{Gradient} \times 1000 \text{-yr}}{\text{Pore}_\text{Soil}}$$

$$\text{Dist}_\text{Soil} = 793.772 \text{-ft}$$

$$\text{Relative Distance} := \frac{\text{Dist}_\text{Mono}}{\text{Dist}_\text{Soil}}$$

$$\text{Relative Distance} = 1.418 \times 10^{-4}$$

Monolith lengths travel in 1,000 years for an internal water particle:

$$\text{Monolith}_\text{Lengths internal} := \frac{\text{Dist}_\text{Mono}}{L}$$

$$\text{Monolith}_\text{Lengths internal} = 1.608 \times 10^{-4}$$

Monolith lengths travel in 1,000 years for an external water particle:

$$\text{Monolith}_\text{Lengths external} := \frac{\text{Dist}_\text{Soil}}{\text{Half}_\text{Mono}_\text{Perimeter}}$$

$$\text{Monolith}_\text{Lengths external} = 1.044$$

$$\text{Ratio External over Internal Length} := \frac{\text{Monolith}_\text{Lengths external}}{\text{Monolith}_\text{Lengths internal}}$$

$$\text{Ratio External over Internal Length} = 6.496 \times 10^{3}$$

Relative distance traveled by a water particle around the monolith rather than through it.
Comparison of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith: Darcy permeability of the site soil:

\[
\begin{align*}
D_{\text{mono}} &= 1 \times 10^{-7} \text{cm/s} \\
D_{\text{soil}} &= 4.6 \times 10^{-3} \text{cm/s}
\end{align*}
\]

\[
\begin{align*}
P_{\text{mono}} &= 0.23 \\
P_{\text{soil}} &= 0.3
\end{align*}
\]

\[
\begin{align*}
L &= 700 \text{ ft} \\
W &= 60 \text{ ft}
\end{align*}
\]

\[
\begin{align*}
\text{Gradient} &= 0.00005
\end{align*}
\]

\[
\begin{align*}
\text{Half Mono Perimeter} &= L + W \\
\text{Half Mono Perimeter} &= 760 \text{ ft}
\end{align*}
\]

Water particle travel in 1,000 years:

\[
\begin{align*}
\text{Dist}_{\text{mono}} &= \frac{D_{\text{mono}} \times \text{Gradient} \times 1000 \text{ yr}}{P_{\text{mono}}} \\
\text{Dist}_{\text{mono}} &= 0.023 \text{ ft}
\end{align*}
\]

\[
\begin{align*}
\text{Dist}_{\text{soil}} &= \frac{D_{\text{soil}} \times \text{Gradient} \times 1000 \text{ yr}}{P_{\text{soil}}} \\
\text{Dist}_{\text{soil}} &= 793.772 \text{ ft}
\end{align*}
\]

\[
\begin{align*}
\text{Relative Distance} &= \frac{\text{Dist}_{\text{mono}}}{\text{Dist}_{\text{soil}}} \\
\text{Relative Distance} &= 2.836 \times 10^{-5}
\end{align*}
\]

Monolith lengths travel in 1,000 years for an internal water particle:

\[
\begin{align*}
\text{Monolith Lengths internal} &= \frac{\text{Dist}_{\text{mono}}}{L} \\
\text{Monolith Lengths internal} &= 3.215 \times 10^{-5}
\end{align*}
\]

Monolith lengths travel in 1,000 years for an external water particle:

\[
\begin{align*}
\text{Monolith Lengths external} &= \frac{\text{Dist}_{\text{soil}}}{\text{Half Mono Perimeter}} \\
\text{Monolith Lengths external} &= 1.044
\end{align*}
\]

\[
\begin{align*}
\text{Ratio External over Internal Length} &= \frac{\text{Monolith Lengths external}}{\text{Monolith Lengths internal}}
\end{align*}
\]

Relative distance traveled by a water particle around the monolith rather than through it:

\[
\begin{align*}
\text{Ratio External over Internal Length} &= 3.248 \times 10^4
\end{align*}
\]
Comparison of Groundwater Transport through and around a Monolith at the Kassouf-Kimerling Site

Darcy permeability of Monolith: Darcy permeability of the site soil:

\[ D_{\text{mono}} := 5 \cdot 10^{-8} \text{ cm s}^{-1} \]
\[ D_{\text{soil}} := 4.6 \cdot 10^{-3} \text{ cm s}^{-1} \]

\[ \text{Pore}_{\text{Mono}} := 0.23 \]
\[ \text{Pore}_{\text{Soil}} := 0.3 \]

\[ L := 700-\text{ft} \quad W := 60-\text{ft} \]
\[ \text{Gradient} := 0.00005 \]

\[ \text{Half Mono Perimeter} := L + W \]
\[ \text{Half Mono Perimeter} = 760-\text{ft} \]

Water particle travel in 1,000 years:

\[ \text{Dist}_{\text{Mono}} := \frac{D_{\text{mono}} \cdot \text{Gradient} \cdot 1000-\text{yr}}{\text{Pore}_{\text{Mono}}} \]
\[ \text{Dist}_{\text{Mono}} = 0.011-\text{ft} \]

\[ \text{Dist}_{\text{Soil}} := \frac{D_{\text{soil}} \cdot \text{Gradient} \cdot 1000-\text{yr}}{\text{Pore}_{\text{Soil}}} \]
\[ \text{Dist}_{\text{Soil}} = 793.772-\text{ft} \]

\[ \text{Relative Distance} := \frac{\text{Dist}_{\text{Mono}}}{\text{Dist}_{\text{Soil}}} \]
\[ \text{Relative Distance} = 1.418 \cdot 10^{-5} \]

Monolith lengths travel in 1,000 years for an internal water particle:

\[ \text{Monolith Lengths}_{\text{internal}} := \frac{\text{Dist}_{\text{Mono}}}{L} \]
\[ \text{Monolith Lengths}_{\text{internal}} = 1.608 \cdot 10^{-5} \]

Monolith lengths travel in 1,000 years for an external water particle:

\[ \text{Monolith Lengths}_{\text{external}} := \frac{\text{Dist}_{\text{Soil}}}{\text{Half Mono Perimeter}} \]
\[ \text{Monolith Lengths}_{\text{external}} = 1.044 \]

\[ \text{Ratio External over Internal Length} := \frac{\text{Monolith Lengths}_{\text{external}}}{\text{Monolith Lengths}_{\text{internal}}} \]

Relative distance traveled by a water particle around the monolith rather than through it.

\[ \text{Ratio External over Internal Length} = 6.496 \cdot 10^{4} \]
Appendix II

Effect of Monolith Diffusion Coefficients on Potential Groundwater Lead Concentrations at the Kassouf-Kimerling Superfund Site
The fractional releases over 1,000 years of leaching and the calculated average concentrations of lead near the monolith surface (assuming an average lead concentration of 2,500 ppm in the soil).

<table>
<thead>
<tr>
<th>Monolith diffusion coefficient, cm²/s</th>
<th>Fraction released after 1,000 years</th>
<th>Average concentration of lead, ppb</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00E-10</td>
<td>0.01499</td>
<td>70</td>
</tr>
<tr>
<td>1.00E-11</td>
<td>0.00474</td>
<td>22</td>
</tr>
<tr>
<td>5.00E-12</td>
<td>0.00335</td>
<td>16</td>
</tr>
<tr>
<td>1.00E-12</td>
<td>0.0015</td>
<td>7</td>
</tr>
<tr>
<td>5.00E-13</td>
<td>0.00106</td>
<td>5</td>
</tr>
<tr>
<td>1.00E-13</td>
<td>0.00047</td>
<td>2.2</td>
</tr>
<tr>
<td>5.00E-14</td>
<td>0.00034</td>
<td>1.6</td>
</tr>
</tbody>
</table>

Average Lead Concentrations Over First 1,000 Years as a Function of Monolith Diffusion Coefficients
1,000 Year Release Model for the Kassouf-Kimberling Site

Monolith Dimensions:

<table>
<thead>
<tr>
<th>Length</th>
<th>Width</th>
<th>Depth</th>
<th>Volume</th>
<th>Surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>L := 700 ft</td>
<td>W := 60 ft</td>
<td>D := 10.43 ft</td>
<td>V := L.W.D</td>
<td>S := 2(W.D + L.W + L.D)</td>
</tr>
</tbody>
</table>

\[ V = 4.3806 \times 10^5 \text{ ft}^3 \]

\[ S = 99853.6 \text{ ft}^2 \]

\[ V = 16224 \text{ yd}^3 \]

\[ S = 11095 \text{ yd}^2 \]

Effective diffusion Coefficient:

\[ D_e := 1 \times 10^{-10} \text{ cm}^2 \text{s}^{-1} \]

Surface to Volume:

\[ \frac{S}{V} = 0.00748 \cdot \text{cm}^{-1} \]

Time iteration:

\[ i := 0, 50 \ldots 2000 \]

\[ t_i := i \cdot \text{yr} \]

Infinite slab diffusion model:

\[ F_i := 2 \cdot \frac{S}{V} \sqrt{\frac{t_i}{\pi D_e}} \]

RELEASE FROM 700x60x10.5 ft MONOLITH

FRACTION RELEASED

\[ F_{50} = 0.00335 \]

\[ F_{150} = 0.00581 \]
Calculate Monolith Lead Content

Monolith Weight:

\[
density := 120 \frac{\text{lbs}}{\text{ft}^3} \quad V = 4.3806 \times 10^5 \text{ ft}^3
\]

\[
\text{Mono}_\text{wgt} := \text{density} \cdot V \quad \text{Mono}_\text{wgt} = 5.25672 \times 10^7 \text{ lbs}
\]

\[
\text{Mass}_\text{Dilution} := 1.8
\]

Weight of Lead in Monolith:

\[
\text{Pb}_\text{Mass} := \text{Mono}_\text{wgt} \cdot \text{Pb}_\text{Mono}
\]

\[
\text{Pb}_\text{Mass} = 73010 \text{ lbs}
\]

Average Soil Concentration:

\[
\text{Pb}_\text{Soil} := 2500 \text{ ppm}
\]

Concentration in Monolith:

\[
\text{Pb}_\text{Mono} := \frac{\text{Pb}_\text{Soil}}{1.8}
\]

Lead Released Over 1,000 years

\[
F_{1000} = 0.01499
\]

\[
\text{Pb}_\text{Loss} := \text{Pb}_\text{Mass} \cdot F_{1000}
\]

\[
\text{Pb}_\text{Loss} = 1094.47 \text{ lbs}
\]

Dilution by Groundwater and Rain over a 1,000 Years

Site Darcy permeability:

\[
\text{Permeability} := 4.6 \times 10^{-3} \frac{\text{cm}}{s}
\]

\[
\text{Gradient} := 0.00005
\]

Cross Section of Monolith End:

\[
\text{Cross}_\text{area} := D \cdot (W + 10 \text{ ft})
\]

\[
\text{Cross}_\text{area} = 730.1 \text{ ft}^2
\]

Groundwater Flowing over Monolith:

\[
\text{Horz}_\text{Flux} := \text{Permeability} \cdot \text{Gradient} \cdot \text{Cross}_\text{area}
\]

\[
\text{Horz}_\text{Flux} = 173.86 \text{ ft}^3/\text{yr}
\]

Horizontal Weight in 1,000 years

\[
\text{Horz}_\text{Mass} := 1000 \cdot Y \cdot \text{Horz}_\text{Flux} \cdot \frac{\text{lb}}{\text{ft}^3}
\]

\[
\text{Horz}_\text{Mass} = 1.07793 \times 10^7 \text{ lbs}
\]

Rain falling on the Monolith over 1,000 YEARS

Annual Rainfall:

\[
\text{Rain} := 60 \frac{\text{in}}{Y}
\]

Area of Monolith and Berms:

\[
\text{Top}_\text{Area} := (W + 10 \text{ ft}) \cdot (L + 10 \text{ ft})
\]

Annual Volume of Rain on Monolith:

\[
\text{Rain}_\text{Year} := \text{Rain} \cdot \text{Top}_\text{Area}
\]

\[
\text{Rain}_\text{Year} = 2.485 \times 10^5 \text{ ft}^3/\text{Y}
\]
Total Pounds of Water over and around the Monolith in 1,000 Years

\[ \text{Horz\_Mass} = 1.07793 \cdot 10^7 \cdot \text{lbs} \quad \text{Vert\_Mass} = 1.55064 \cdot 10^{10} \cdot \text{lbs} \]

\[ \text{Horz\_Mass} + \text{Vert\_Mass} = 1.55172 \cdot 10^{10} \cdot \text{lbs} \]

Average Maximum Lead Concentration over the First 1,000 Years

\[ \text{Ave\_Conc} := \frac{\text{Pb\_Loss}}{\text{Horz\_Mass} + \text{Vert\_Mass}} \quad \text{Ave\_Conc} = 0.07053 \cdot \text{ppm} \]

National Drinking Water Standards \(= 0.015 \text{ ppm}\)

Tennessee Water Quality Standards \(= 0.05 \text{ ppm}\)

Detection Limits Ion Coupled Plasma Method \(= 0.2 \text{ ppm}\)

Detection Limits Graphite Furnace Atomic Adsorption \(= 0.004 \text{ ppm}\)
Monolith Dimensions:

<table>
<thead>
<tr>
<th>Length</th>
<th>Width</th>
<th>Depth</th>
<th>Volume</th>
<th>Surface</th>
</tr>
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<tbody>
<tr>
<td>L := 700 ft</td>
<td>W := 60 ft</td>
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<td>V := L \cdot W \cdot D</td>
<td>S := 2 \cdot (W \cdot D + L \cdot W + L \cdot D)</td>
</tr>
</tbody>
</table>

Effective diffusion Coefficient:

\[ D_e := 1 \cdot 10^{-11} \text{m}^2 \text{s}^{-1} \]

Surface to Volume:

\[ \frac{S}{V} = 0.00748 \text{m}^{-1} \]

Time iteration:

\[ i := 0, 50 \ldots 2000 \]

Infinite slab diffusion model:

\[ F_i := 2 \cdot \frac{S}{V} \sqrt{\frac{t_i}{D_e}} \]

RELEASE FROM 700x60x10.5 ft MONOLITH

FRACTION RELEASED

\[ F_{50} = 0.00106 \quad F_{150} = 0.00184 \]

\[ F_{500} = 0.00225 \quad F_{1500} = 0.00474 \]
Calculate Monolith Lead Content

Monolith Weight:

\[
\text{density} := \frac{120 \text{ lbs}}{\text{ft}^3} \quad V = 4.3806 \cdot 10^5 \text{ ft}^3
\]

\[
\text{Mono_wgt} := \text{density} \cdot V \quad \text{Mono_wgt} = 5.25672 \cdot 10^7 \text{ lbs}
\]

\[
\text{Mass_Dilution} := 1.8
\]

Weight of Lead in Monolith:

\[
\text{Pb_Mass} := \text{Mono_wgt} \cdot \text{Pb_Mono}
\]

\[
\text{Pb_Mass} = 73010 \text{ lbs}
\]

Average Soil Concentration:

\[
\text{Pb_Soil} := 2500 \text{ ppm}
\]

Concentration in Monolith

\[
\text{Pb_Mono} := \frac{\text{Pb_Soil}}{1.8}
\]

Lead Released Over 1,000 years

\[
\text{F}_{1000} = 0.00474
\]

\[
\text{Pb_Loss} := \text{Pb_Mass} \cdot \text{F}_{1000}
\]

\[
\text{Pb_Loss} = 346.1 \text{ lbs}
\]

Dilution by Groundwater and Rain over a 1,000 Years

Site Darcy permeability:

\[
\text{Permeability} := 4.6 \cdot 10^{-3} \text{ cm/s}
\]

\[
\text{Gradient} := 0.00005
\]

Cross Section of Monolith End:

\[
\text{Cross_area} := D \cdot (W + 10 \text{ ft})
\]

\[
\text{Cross_area} = 730.1 \text{ ft}^2
\]

Groundwater Flowing over Monolith:

\[
\text{Horz_Flux} := \text{Permeability} \cdot \text{Gradient} \cdot \text{Cross_area}
\]

\[
\text{Horz_Flux} = 173.86 \text{ ft}^3 \text{ yr}^{-1}
\]

Horizontal Weight in 1,000 years

\[
\text{Horz_Mass} := 1000 \cdot \text{Y} \cdot \text{Horz_Flux} \cdot 62 \frac{\text{lbs}}{\text{ft}^3}
\]

\[
\text{Horz_Mass} = 1.07793 \cdot 10^7 \text{ lbs}
\]

Rain falling on the Monolith over 1,000 YEARS

Annual Rainfall:

\[
\text{Rain} := 60 \frac{\text{in}}{\text{Y}}
\]

Annual Volume of Rain on Monolith:

\[
\text{Rain-Year} := \text{Rain} \cdot \text{Top_Area}
\]

\[
\text{Rain-Year} = 2.485 \cdot 10^5 \text{ ft}^3 \text{ Y}^{-1}
\]
Total Pounds of Water over and around the Monolith in 1,000 Years

\[ \text{Horz}_\text{Mass} = 1.07793 \times 10^7 \text{ lbs} \quad \text{Vert}_\text{Mass} = 1.55064 \times 10^{10} \text{ lbs} \]

\[ \text{Horz}_\text{Mass} + \text{Vert}_\text{Mass} = 1.55172 \times 10^{10} \text{ lbs} \]

Average Maximum Lead Concentration over the First 1,000 Years

\[ \text{Ave}_\text{Conc} = \frac{\text{Pb}_\text{Loss}}{\text{Horz}_\text{Mass} + \text{Vert}_\text{Mass}} \]

\[ \text{Ave}_\text{Conc} = 0.0223 \text{ ppm} \]

National Drinking Water Standards = 0.015 ppm

Tennessee Water Quality Standards = 0.05 ppm

Detection Limits Ion Coupled Plasma Method = 0.2 ppm

Detection Limits Graphite Furnace Atomic Adsorption = 0.004 ppm
Monolith Dimensions:

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<td></td>
<td></td>
</tr>
<tr>
<td>V = 16224 \text{ yd}^3</td>
<td>S = 11095 \text{ yd}^2</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Effective diffusion Coefficient:

\[ D_e := 5 \times 10^{-12} \text{ cm}^2 / \text{s} \]

Surface to Volume:

\[ \frac{S}{V} = 0.00748 \text{ cm}^{-1} \]

Time iteration

\[ i := 0, 50 \ldots 2000 \]
\[ t_i := i \cdot \text{yr} \]

Infinite slab diffusion model:

\[ F_i := 2 \cdot S \cdot \sqrt{\frac{t_i}{V} \cdot D_e} \]

RELEASE FROM 700x60x10.5 ft MONOLITH

FRACTION RELEASED

\[ F_{50} = 0.00075 \quad F_{150} = 0.0013 \]
Calculate Monolith Lead Content

Monolith Weight:

\[ \text{density} := 120 \text{ lbs/ft}^3 \]

\[ V = 4.3806 \times 10^5 \text{ ft}^3 \]

\[ \text{Mono}_\text{wgt} := \text{density} \times V \]

\[ \text{Mono}_\text{wgt} = 5.25672 \times 10^7 \text{ lbs} \]

\[ \text{Mass Dilution} := 1.8 \]

\[ \text{Weight of Lead in Monolith}: \]

\[ \text{Pb}_\text{Mass} := \text{Mono}_\text{wgt} \times \text{Mass Dilution} \]

\[ \text{Pb Mass} = 73010 \text{ lbs} \]

Average Soil Concentration:

\[ \text{Pb}_\text{Soil} := 2500 \text{ ppm} \]

Concentration in Monolith

\[ \text{Pb}_\text{Mono} := \frac{\text{Pb}_\text{Soil}}{1.8} \]

Lead Released Over 1,000 years

\[ F_{1000} = 0.00335 \]

\[ \text{Pb Loss} := \text{Pb Mass} \times F_{1000} \]

\[ \text{Pb Loss} = 244.73 \text{ lbs} \]

Dilution by Groundwater and Rain over a 1,000 Years

Site Darcy permeability:

\[ \text{Permeability} := 4.6 \times 10^{-3} \text{ cm/s} \]

\[ \text{Gradient} := 0.00005 \]

Cross Section of Monolith End:

\[ \text{Cross area} := D \times (W + 10 \text{-ft}) \]

\[ \text{Cross area} = 730.1 \text{ ft}^2 \]

Groundwater Flowing over Monolith:

\[ \text{Horz Flux} := \text{Permeability} \times \text{Gradient} \times \text{Cross area} \]

\[ \text{Horz Flux} = 173.86 \frac{\text{ft}^3}{\text{yr}} \]

Horzontal Weight in 1,000 years

\[ \text{Horz Mass} := 1000 \times \text{Y} \times \text{Horz Flux} \times 62.4 \frac{\text{lbs}}{\text{ft}^3} \]

\[ \text{Horz Mass} = 1.07793 \times 10^7 \text{ lbs} \]

Rain falling on the Monolith over 1,000 YEARS

Annual Rainfall:

\[ \text{Rain} := 60 \frac{\text{in}}{\text{Y}} \]

Area of Monolith and Berms:

\[ \text{Top Area} := (W + 10 \text{-ft}) \times (L + 10 \text{-ft}) \]

Annual Volume of Rain on Monolith:

\[ \text{Rain Year} := \text{Rain} \times \text{Top Area} \]

\[ \text{Rain Year} = 2.485 \times 10^5 \frac{\text{ft}^3}{\text{Y}} \]
Total Pounds of Water over and around the Monolith in 1,000 Years

\[ \text{Horz\_Mass} = 1.07793 \cdot 10^7 \cdot \text{lbs} \]
\[ \text{Vert\_Mass} = 1.55064 \cdot 10^{10} \cdot \text{lbs} \]

\[ \text{Horz\_Mass} + \text{Vert\_Mass} = 1.55172 \cdot 10^{10} \cdot \text{lbs} \]

Average Maximum Lead Concentration over the First 1,000 Years

\[ \text{Ave\_Conc} := \frac{\text{Pb\_Loss}}{\text{Horz\_Mass} + \text{Vert\_Mass}} \]

\[ \text{Ave\_Conc} = 0.01577 \cdot \text{ppm} \]

\[ \text{Ave\_Conc} = 0.01577 \cdot \text{ppm} \]

National Drinking Water Standards = 0.015 ppm

Tennessee Water Quality Standards = 0.05 ppm

Detection Limits Ion Coupled Plasma Method = 0.2 ppm

Detection Limits Graphite Furnace Atomic Adsorption = 0.004 ppm
Monolith Dimensions:

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<td>V := L·W·D</td>
<td>S := 2·(W·D + L·W + L·D)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>V := 4.3306·10^5 ft^3</td>
<td>S := 99853.6 ft^2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>V := 16224 ·yd^3</td>
<td>S := 11095 ·yd^2</td>
</tr>
</tbody>
</table>

Effective diffusion Coefficient:

\[ D_e := 1 \cdot 10^{-12} \frac{\text{cm}^2}{\text{s}} \]

Surface to Volume:

\[ \frac{S}{V} = 0.00748 \cdot \text{cm}^{-1} \]

Time iteration:

\[ i := 0, 50 \ldots 2000 \]

\[ t_i := i \cdot \text{yr} \]

Infinite slab diffusion model:

\[ F_i := 2 \cdot \frac{S}{V} \sqrt{\frac{t_i}{D_e \cdot \pi}} \]

**RELEASE FROM 700x60x10.5 ft MONOLITH**

<table>
<thead>
<tr>
<th>Fraction Released</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0004</td>
<td>0</td>
</tr>
<tr>
<td>0.00034</td>
<td>50</td>
</tr>
<tr>
<td>0.00058</td>
<td>150</td>
</tr>
</tbody>
</table>

\[ F_{50} = 0.00034 \quad F_{150} = 0.00058 \]
Calculate Monolith Lead Content

Monolith Weight:

\[ \text{density} = \frac{120 \text{ lbs}}{\text{ft}^3} \]

\[ V = 4.3806 \times 10^5 \text{ ft}^3 \]

\[ \text{Mono_wgt} = \text{density} \times V \]

\[ \text{Mono_wgt} = 5.2562 \times 10^7 \text{ lbs} \]

\[ \text{Mass_Dilution} = 1.8 \]

Weight of Lead in Monolith:

\[ \text{Pb_Mass} = \text{Mono_wgt} \times \text{Pb_Mono} \]

\[ \text{Pb_Mass} = 73010 \text{ lbs} \]

Average Soil Concentration:

\[ \text{Pb}_\text{Soil} = 2500 \text{ ppm} \]

Concentration in Monolith

\[ \text{Pb}_\text{Mono} = \frac{\text{Pb}_\text{Soil}}{1.8} \]

Lead Released Over 1,000 years

\[ F_{1000} = 0.0015 \]

\[ \text{Pb}_\text{Loss} = \text{Pb}_\text{Mass} \times F_{1000} \]

\[ \text{Pb}_\text{Loss} = 109.45 \text{ lbs} \]

Dilution by Groundwater and Rain over a 1,000 Years

Site Darcy permeability:

\[ \text{Permeability} = 4.6 \times 10^{-3} \text{ cm/s} \]

\[ \text{Gradient} = 0.00005 \]

Cross Section of Monolith End:

\[ \text{Cross_area} = D \times (W + 10) \text{ ft}^2 \]

\[ \text{Cross_area} = 730.1 \text{ ft}^2 \]

Groundwater Flowing over Monolith:

\[ \text{Horz Flux} = \text{Permeability} \times \text{Gradient} \times \text{Cross_area} \]

\[ \text{Horz Flux} = 173.86 \text{ ft}^3/\text{yr} \]

Horzontal Weight in 1,000 years

\[ \text{Horz Mass} = 1000 \times \text{Horz Flux} \times \frac{62\text{ lbs}}{\text{ft}^3} \]

\[ \text{Horz Mass} = 1.07793 \times 10^7 \text{ lbs} \]

Rain falling on the Monolith over 1,000 YEARS

Annual Rainfall:

\[ \text{Rain} = 60 \frac{\text{in}}{\text{Y}} \]

Area of Monolith and Berms:

\[ \text{Top Area} = (W + 10) \times (L + 10) \text{ ft} \]

Annual Volume of Rain on Monolith:

\[ \text{Rain Year} = \text{Rain} \times \text{Top Area} \]

\[ \text{Rain Year} = 2.485 \times 10^5 \text{ ft}^3/\text{yr} \]
Total Pounds of Water over and around the Monolith in 1,000 Years

\[ \text{Horz\_Mass} = 1.07793 \times 10^7 \text{ lbs} \quad \text{Vert\_Mass} = 1.55064 \times 10^{10} \text{ lbs} \]

\[ \text{Horz\_Mass} + \text{Vert\_Mass} = 1.55172 \times 10^{10} \text{ lbs} \]

Average Maximum Lead Concentration over the First 1,000 Years

\[ \text{Ave\_Conc} = \frac{\text{Pb\_Loss}}{\text{Horz\_Mass} + \text{Vert\_Mass}} \]

\[ \text{Ave\_Conc} = 0.00705 \text{ ppm} \]

National Drinking Water Standards = 0.015 ppm

Tennessee Water Quality Standards = 0.05 ppm

Detection Limits Ion Coupled Plasma Method = 0.2 ppm

Detection Limits Graphite Furnace Atomic Adsorption = 0.004 ppm
Monolith Dimensions:

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<td>V := L * W * D</td>
<td>S := 2 * (W * D + L * W + L * D)</td>
</tr>
</tbody>
</table>

\[
V = 4.3806 \times 10^5 \text{ ft}^3 \\
S = 99853.6 \text{ ft}^2 \\
V = 16224 \text{ yd}^3 \\
S = 11095 \text{ yd}^2
\]

Effective diffusion Coefficient:

\[
D_e := 5 \times 10^{-13} \text{ cm}^2 / \text{s}
\]

Surface to Volume:

\[
\frac{S}{V} = 0.00748 \text{ cm}^{-1}
\]

Time iteration:

\[
i := 0, 50, 2000
\]

\[
t_i := i \text{ yr}
\]

Infinite slab diffusion model:

\[
F_i := 2 \frac{S}{V} \sqrt{\frac{t_i}{D_e \pi}}
\]

RELEASE FROM 700x60x10.5 ft MONOLITH

FRACTION RELEASED

\[
F_{50} = 0.00024 \\
F_{150} = 0.00041
\]

years
Calculate Monolith Lead Content

Monolith Weight:

\[ \text{density} = \frac{120 \text{ lbs}}{\text{ft}^3} \quad V = 4.3806 \times 10^5 \text{ ft}^3 \]

\[ \text{Mono_wgt} = \text{density} \cdot V \quad \text{Mono_wgt} = 5.25672 \times 10^7 \text{ lbs} \]

\[ \text{Mass_Dilution} = 1.8 \]

Weight of Lead in Monolith:

\[ \text{Pb_Mass} = \text{Mono_wgt} \cdot \text{Pb_Mono} \]

\[ \text{Pb_Mass} = 73010 \text{ lbs} \]

Average Soil Concentration:

\[ \text{Pb_Soil} = 2500 \text{ ppm} \]

Concentration in Monolith

\[ \text{Pb_Mono} = \frac{\text{Pb_Soil}}{1.8} \]

Lead Released Over 1,000 years

\[ \text{F}_{1000} = 0.00106 \]

\[ \text{Pb_Loss} = \text{Pb_Mass} \cdot \text{F}_{1000} \]

\[ \text{Pb_Loss} = 77.39 \text{ lbs} \]

Dilution by Groundwater and Rain over a 1,000 Years

Site Darcy permeability:

\[ \text{Permeability} = 4.6 \times 10^{-3} \text{ cm/s} \]

\[ \text{Gradient} = 0.00005 \]

Cross Section of Monolith End:

\[ \text{Cross_area} = D \cdot (W + 10^{-5}) \]

\[ \text{Cross_area} = 730.1 \text{ ft}^2 \]

Groundwater Flowing over Monolith:

\[ \text{Horz_Flux} = \text{Permeability} \cdot \text{Gradient} \cdot \text{Cross_area} \]

\[ \text{Horz_Flux} = 173.86 \text{ ft}^3/\text{yr} \]

Horzontal Weight in 1,000 years

\[ \text{Horz_Mass} = \frac{1000 \cdot \text{Y} \cdot \text{Horz_Flux} - 62 \text{ lbs}}{\text{ft}^3} \]

\[ \text{Horz_Mass} = 1.07793 \times 10^7 \text{ lbs} \]

Rain falling on the Monolith over 1,000 YEARS

Annual Rainfall:

\[ \text{Rain} = 60 \frac{\text{in}}{\text{Y}} \]

Area of Monolith and Berms:

\[ \text{Top_Area} = (W + 10^{-5}) \cdot (L + 10^{-5}) \]

Annual Volume of Rain on Monolith:

\[ \text{Rain}_\text{Year} = \text{Rain} \cdot \text{Top_Area} \]

\[ \text{Rain}_\text{Year} = 2.485 \times 10^5 \frac{\text{ft}^3}{\text{Y}} \]
Total Pounds of Water over and around the Monolith in 1,000 Years

\[ \text{Horz. Mass} = 1.07793 \times 10^7 \text{ lbs} \]
\[ \text{Vert. Mass} = 1.55064 \times 10^{10} \text{ lbs} \]
\[ \text{Horz. Mass} + \text{Vert. Mass} = 1.55172 \times 10^{10} \text{ lbs} \]

Average Maximum Lead Concentration over the First 1,000 Years

\[ \text{Ave. Conc} := \frac{\text{Pb. Loss}}{\text{Horz. Mass} + \text{Vert. Mass}} \]
\[ \text{Ave. Conc} = 0.00499 \text{ ppm} \]

National Drinking Water Standards = 0.015 ppm

Tennessee Water Quality Standards = 0.05 ppm

Detection Limits Ion Coupled Plasma Method = 0.2 ppm

Detection Limits Graphite Furnace Atomic Adsorption = 0.004 ppm
1,000 Year Release Model for the Kassouf-Kimberling Site

Monolith Dimensions:

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<tr>
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Effective diffusion Coefficient:

\[ D_e := 1 \times 10^{-13} \text{ cm}^2 / \text{s} \]

Surface to Volume:

\[ \frac{S}{V} = 0.00748 \text{ cm}^{-1} \]

Time iteration:

\( i := 0, 50 ..., 2000 \)

\( t_i := i \text{ yr} \)

Infinite slab diffusion model:

\[ F_i := 2 \cdot \frac{S}{V} \sqrt{\frac{t_i}{D_e \pi}} \]

RELEASE FROM 700x60x10.5 ft MONOLITH

FRACTION RELEASED

\( F_{50} = 0.00011 \)

\( F_{150} = 0.00018 \)
Calculate Monolith Lead Content

Monolith Weight:

\[
\text{density} = 120 \frac{\text{lbs}}{\text{ft}^3} \quad V = 4.3806 \times 10^5 \text{ ft}^3
\]

\[
\text{Mono_wgt} = \text{density} \times V = 5.25672 \times 10^7 \text{ lbs}
\]

\[
\text{Mass_Dilution} = 1.8
\]

Weight of Lead in Monolith:

\[
\text{Pb_Mass} = \text{Mono_wgt} \times \text{Pb_Mono}
\]

\[
\text{Pb_Mass} = 73010 \text{ lbs}
\]

Average Soil Concentration:

\[
\text{Pb_Soil} = 2500 \text{ ppm}
\]

Concentration in Monolith:

\[
\text{Pb_Mono} = \frac{\text{Pb_Soil}}{1.8}
\]

Lead Released Over 1,000 years:

\[
F_{1000} = 0.00047
\]

\[
\text{Pb_Loss} = \text{Pb_Mass} \times F_{1000}
\]

\[
\text{Pb_Loss} = 34.61 \text{ lbs}
\]

Dilution by Groundwater and Rain over a 1,000 Years

Site Darcy permeability:

\[
\text{Permeability} = 4.6 \times 10^{-3} \frac{\text{cm}}{s}
\]

Cross Section of Monolith End:

\[
\text{Cross_area} = D \times (W + 10 \text{ ft})
\]

\[
\text{Cross_area} = 730.1 \text{ ft}^2
\]

Groundwater Flowing over Monolith:

\[
\text{Horz_Flux} = \text{Permeability} \times \text{Gradient} \times \text{Cross_area}
\]

\[
\text{Horz_Flux} = 173.86 \frac{\text{ft}^3}{\text{yr}}
\]

Horizontal Weight in 1,000 years:

\[
\text{Horz_Mass} = 1000 \times \text{Horz_Flux} \times 62 \frac{\text{lbs}}{\text{ft}^3}
\]

\[
\text{Horz_Mass} = 1.07793 \times 10^7 \text{ lbs}
\]

Rain falling on the Monolith over 1,000 YEARS

Annual Rainfall:

\[
\text{Rain} = 60 \frac{\text{n}}{\text{Y}}
\]

Area of Monolith and Berms:

\[
\text{Top.Area} = (W + 10 \text{ ft}) \times (L + 10 \text{ ft})
\]

Annual Volume of Rain on Monolith:

\[
\text{Rain-Year} = \text{Rain} \times \text{Top.Area}
\]

\[
\text{Rain-Year} = 2.485 \times 10^5 \frac{\text{ft}^3}{\text{Y}}
\]
Total Pounds of Water over and around the Monolith in 1,000 Years

\[ H_{\text{Horz Mass}} = 1.07793 \times 10^7 \text{ lbs} \]

\[ V_{\text{Vert Mass}} = 1.55064 \times 10^{10} \text{ lbs} \]

\[ H_{\text{Horz Mass}} + V_{\text{Vert Mass}} = 1.55172 \times 10^{10} \text{ lbs} \]

Average Maximum Lead Concentration over the First 1,000 Years

\[ \text{Ave Conc} = \frac{\text{Pb Loss}}{H_{\text{Horz Mass}} + V_{\text{Vert Mass}}} \]

\[ \text{Ave Conc} = 0.00223 \text{ ppm} \]

National Drinking Water Standards = 0.015 ppm

Tennessee Water Quality Standards = 0.05 ppm

Detection Limits Ion Coupled Plasma Method = 0.2 ppm

Detection Limits Graphite Furnace Atomic Adsorption = 0.004 ppm
1,000 Year Release Model for the Kassouf-Kimberling Site

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<td>V := L \times W \times D</td>
<td>S := 2 \times (W \times D + L \times W + L \times D)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>V = 4.3606 \times 10^5 ft^3</td>
<td>S = 99853.6 ft^2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>V = 16224 yd^3</td>
<td>S = 11095 yd^2</td>
</tr>
</tbody>
</table>

Effective diffusion Coefficient:

\[ D_e := 5 \times 10^{-14} \text{ cm}^2 \text{s}^{-1} \]

Surface to Volume:

\[ \frac{S}{V} = 0.00748 \text{ cm}^{-1} \]

Infinite slab diffusion model:

\[ F_i = \frac{2 S}{V} \sqrt{\frac{t}{D_e \pi}} \]

RELEASE FROM 700x60x10.5 ft MONOLITH

FRACTION RELEASED

\[ F_{50} = 0.00007 \quad F_{150} = 0.00013 \]

years
Calculate Monolith Lead Content

Monolith Weight:

\[
\text{density} := 120 \text{ lbs/ft}^3 \\
V = 4.3806 \times 10^5 \text{ ft}^3 \\
\text{Mono_wgt} := \text{density} \times V \\
\text{Mono_wgt} = 5.25672 \times 10^7 \text{ lbs} \\
\text{Mass_Dilution} := 1.8 \\
\text{Pb_Mass} := \text{Mono_wgt} \times \text{Pb_Mono} \\
\text{Pb_Mass} = 73010 \text{ lbs}
\]

Average Soil Concentration:

\[
\text{Pb_Soil} := 2500 \text{ ppm} \\
\text{Concntration in Monolith} \\
\frac{\text{Pb_Mono}}{1.8} \\
\text{Lead Released Over 1,000 years} \\
F_{1000} = 0.00034 \\
\text{Pb_Loss} := \text{Pb_Mass} \times F_{1000} \\
\text{Pb_Loss} = 24.47 \text{ lbs}
\]

Dilution by Groundwater and Rain over a 1,000 Years

Site Darcy permeability:

\[
\text{Permeability} := 4.6 \times 10^{-3} \text{ cm/s} \\
\text{Gradient} := 0.00005
\]

Cross Section of Monolith End:

\[
\text{Cross_area} := D \times (W + 10 \text{ ft}) \\
\text{Cross_area} = 730.1 \text{ ft}^2
\]

Groundwater Flowing over Monolith:

\[
\text{Horz_Flux} := \text{Permeability} \times \text{Gradient} \times \text{Cross_area} \\
\text{Horz_Flux} = 173.86 \text{ ft}^3 / \text{yr}
\]

Horizontal Weight in 1,000 years

\[
\text{Horz_Mass} := 1000 \times Y \times \text{Horz_Flux} \times 62 \text{ lbs/ft}^3 \\
\text{Horz_Mass} = 1.07793 \times 10^7 \text{ lbs}
\]

Rain falling on the Monolith over 1,000 YEARS

Annual Rainfall:

\[
\text{Rain} := 60 \text{ in/Y} \\
\text{Area of Monolith and Berms:} \\
\text{Top_Area} := (W + 10 \text{ ft}) \times (L + 10 \text{ ft})
\]

Annual Volume of Rain on Monolith:

\[
\text{Rain_Year} := \text{Rain} \times \text{Top_Area} \\
\text{Rain_Year} = 2.435 \times 10^5 \text{ ft}^3 / \text{Y}
\]
Total Pounds of Water over and around the Monolith in 1,000 Years

\[ \text{Horz\_Mass} = 1.07793 \times 10^7 \text{ lbs} \quad \text{Vert\_Mass} = 1.55064 \times 10^{10} \text{ lbs} \]

\[ \text{Horz\_Mass} + \text{Vert\_Mass} = 1.55842 \times 10^{10} \text{ lbs} \]

Average Maximum Lead Concentration over the First 1,000 Years

\[ \text{Ave\_Conc} := \frac{\text{Pb\_Loss}}{\text{Horz\_Mass} + \text{Vert\_Mass}} \]

\[ \text{Ave\_Conc} = 0.00158 \text{ ppm} \]

National Drinking Water Standards = 0.015 ppm

Tennessee Water Quality Standards = 0.05 ppm

Detection Limits Ion Coupled Plasma Method = 0.2 ppm

Detection Limits Graphite Furnace Atomic Adsorption = 0.004 ppm